2: How to apply irrigation

Deciding how to apply irrigation first requires answers to a couple of key questions

2.1 What quantity of water is required?

Measuring *evapotranspiration (ET)* is central to determining how much irrigation is required for an individual crop. There are a number of ways in which ET can be determined. In a potted plant this could be determined by recording the weight difference of the combined plant and pot weight each day. The difference in weight, minus the weight of any water applied through irrigation or rain, is the amount of water lost through *ET* via the leaf *stomata* each day. This method describes the use of a *lysimeter*. For obvious reasons this method can not be used in the field, but it is used in research projects to determine water use, plant response to specific water stress conditions, and determination of crop coefficients (see below).

Below is an overview of *ET* and how plant water use may be calculated from basic *meteorological* data. This information can then be used to calculate plant water use and therefore irrigation requirement for the crop of interest.

For a more detailed description of *ET* please refer to http://www.fao.org/docrep/X0490E/x0490e00.htm.

2.1.1. Reference ET_0

Reference ET (ET_0) is a measure which incorporates climatic variables to determine *ET* of a reference surface. This reference surface is usually grass. This value is then multiplied by a *crop coefficient* (K_c) to determine the crop *evapotranspiration* (ET_c) and therefore water usage of the specific crop of interest.

2.1.1.1 Values of ET_0 for growers to use

This generally requires calculation using the Penman-Montieth equation which incorporates *meteorological* information (windspeed, radiation, air temperature and air humidity) that is routinely recorded at numerous weather stations located in the key growing regions of New Zealand. Because the use of the Penman-Montieth equation is quite complex it is not a calculation growers will routinely do for their individual properties. However, the New Zealand meteorological service measures all parameters required for the calculation of ET_0 using the Penman-Montieth equation and so these data are readily available for growers within New Zealand. In the Hawkes Bay the local news paper, Hawkes Bay Today, publishes daily ET_0 throughout the year. In Central Otago the following link gives average values of daily ET_0 during the growing season recorded at Lauder, Central Otago. http://land.orc.govt.nz/landinfo/showsite.asp?s=9 .

2.1.1.2 Crop coefficients

Fig. 1 illustrates the concept behind *crop coefficients*. As a crop develops the leaf area increase and so to does the potential for *evapotranspiration* from the crop surface. The illustration below represents an annual crop which develops rapidly over the season. In a perennial crop such as summerfruit the principles are the same, as the crop develops leaves in the spring, the *crop coefficient* (K_c) steadily increases. During the middle of the season, when canopies are fully developed, plant water use is at a maximum. As autumn begins and leaves begin to drop, the *crop coefficient* (K_c) also drops away.

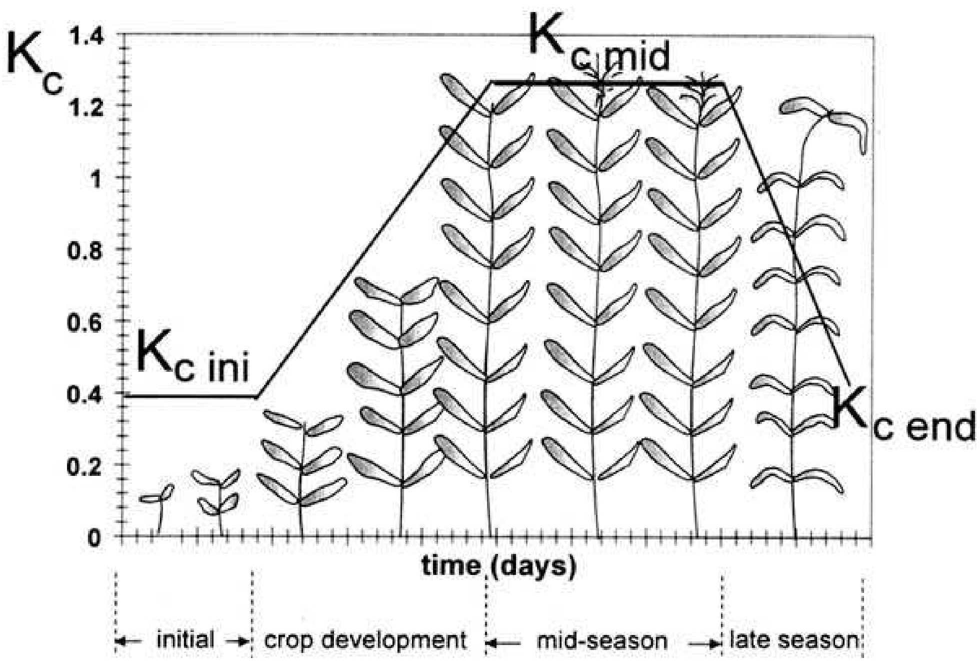


Fig. 1. Seasonal variation in crop coefficient as a plant develops.

Crop coefficients are often more than the reference *evapotranspiration* (ET_0) during the middle of the season. This is due not only to the canopy architecture and the leaf surface area compared to *reference ET* (ET_0,) which is usually grass, but also to the inter-row cover, whether this be bare soil or grass sward. If the inter-row is bare soil then evaporation from this surface is very high if the soil is wet but drops quickly to minimal values as the soil surface dries out. If the inter-row is grassed then this also needs to be incorporated into the total calculated value of ET from the crop system. In the table below we have included values that incorporate a grass sward in the orchard system as this is the most likely scenario for summerfruit growers in New Zealand.

Table 1 below outlines example *crop coefficients* used at the beginning, mid and end of the season. These coefficients are not exact but do give a relative indication of crop water use throughout the season and they provide a good basis for determining *crop evapotranspiration* (ET_c).

Table 1. Beginning, mid and end of season *crop coefficients (Kc)*, and mean maximum plant heights for non stressed, well-managed crops in sub-humid climates. Obtained from the FAO guidelines.

Crop	K_c beginning	K_c mid	K_c end	Maximum Crop Height (m)

Cherries				
active ground cover, killing frost	0.50	1.20	0.95	4
active ground cover, no frosts	0.80	1.20	0.85	4
Apricots, Peaches, Nectarines, Plums				
active ground cover, killing frost	0.50	1.15	0.90	3
active ground cover, no frosts	0.80	1.15	0.85	3

These values presented in Table 1 above give an approximate average K_c for the season of between 0.7-0.85. These values are in line with consultant recommendations in the Hawkes Bay region.

2.1.1.3 Calculating *crop evapotranspiration ET_c* of your crop using *crop coefficients (K_c)* and *reference ET_0* values

The equation below illustrates how ET_0 and K_c can be used to calculate *crop evapotranspiration (ET_c)*

$ET_c = ET_0 \times K_c$

Where : ET_c = crop ET, ET_0 = reference ET, K_c = Crop coefficient

2.1.2 Soil water balance

2.1.2.1 Tensiometers

Tensiometers measure moisture content of the soil by determining the water potential as a pressure. A lower number (more negative pressure) indicates increased difficulty for the plant to extract water from the soil. A less negative number indicates a higher soil water potential and easier uptake of water by the plant.

Tensiometers can either be installed permanently in the ground or portable devices can be used. Two soil moisture levels are used to determine when irrigation is required and when to stop irrigating. When the pre-determined minimum soil moisture is reached, termed *stress point* or *wilting point,* irrigation is applied until tensiometer readings indicate that the maximum soil moisture content, or *field capacity,* has been reached.

Because Tensiometers assess how difficult it is for plants to extract water from the soil, they may be sometimes preferred over other devices which record actual amount of water present within the soil.

It is critical to remember that not all water present within the root zone of a plant can be accessed by that plant. An example is sandy soil which does not hold very much water; most of that water may be extracted by plants as the sand particles are large and the ability of these large particles to hold water is less than a finer material. A clay soil, which is made up of very fine silt particles, may hold a lot of water but much of this water is so tightly bound to the particles that it cannot be extracted by the plant roots. A tensiometer gives you a good guide as to the amount of water that may be available for plant uptake, also known as plant available water.

Fig. 2. Tensiometers showing pressure gauge and ceramic cup at the base

In order to use tensiometers to schedule irrigation, the devices must be well placed to represent the soil water tension (or the relative strength with which the soil holds moisture), within the effective plant root zone. Ideal placement of tensiometers would be within 0.5-1m from the base of the trunk towards the inter-row space and to a depth of at least 600mm.
It is also important to calibrate tensiometers for the soils that are to be measured. Calibration establishes the level of plant available water in the soil which corresponds to values of soil water tension recorded by the tensiometer. The process is simple but a little time consuming. To build a calibration curve for your soil types requires recording of tensiometer values at a range of soil moisture levels from *field capacity* through to *wilting point*. A practical way to do this is to begin recording tensiometer readings shortly after heavy rain or irrigation when you know the soil profile is well wetted. This approximates *field capacity* and soil water tension should be close to 0. As the soil dries tensiometer reading should continue to be recorded as the water tension increases and values recorded by the tensiometer becomes more negative. In parallel samples for the determination of *gravimetric water content* should also be taken. The relationship between gravemetric water content and tensiometer readings will give the range of soil water levels as relates to tensiometer readings. As a rough guide once 50% of the total water recorded by the gravimetric method at field capacity has been removed from the soil that soil is approaching wilting point. This rough guide is OK for all but heavy clays. More information on the calibration of tensiometers may be downloaded from
http://www.bae.ncsu.edu/programs/extension/evans/ag452-3.html

For further discussion on irrigation scheduling with tensiometers visit
http://www.agf.gov.bc.ca/resmgmt/publist/500series/577100-2.pdf

http://www.omafra.gov.on.ca/english/crops/hort/news/hortmatt/2005/14hrt05a4.htm

2.1.2.2 Soil based physical property method

Many growers rely on the appearance and feel of soil to estimate whether or not irrigation is required. Table 2 gives a description of soil, at generalised available water contents, given the observed soil characteristics. Samples are best taken with a soil auger rather than a shovel as an auger gives a uniform sample with depth. Such visual assessment may not seem very scientific but it is a fair indication of plant available soil moisture and it is very quick to carry out once after some practice.

Table 2. Soil texture verses available soil moisture

	soil texture			
available water	coarse (sand, loamy sand)	moderately coarse (sandy loam, fine sandy loam)	medium (loam)	fine (silt loam, clay loam)
100%	leaves wet outline on hand when squeezed.	appears very dark, leaves wet outline on hand; makes a short ribbon.	appears very dark, leaves wet outline on hand: will ribbon out about 2-3 cm.	appears very dark, leaves slight moisture on hand when squeezed: will ribbon out about 6 cm.
70%-80%	appears moist: makes a weak ball.	dark: makes a hard ball.)	quite dark: makes tight plastic ball: ribbons out 1-2 cm	quite dark ribbons and slicks easily: makes plastic ball.
60%-65%	appears slightly moist: forms weak brittle ball.	fairly dark: makes a good ball.	fairly dark: forms firm ball: barely ribbons.	fairly dark: forms firm ball: ribbons 1cm
50%	appears dry: forms very weak ball or will not ball	slightly dark: forms weak ball.	fairly dark: will form ball: slightly crumbly.	Balls easily: small clods flatten out rather than crumble: ribbons slightly.
35%-40%	dry: will not ball.	light color: will not ball or forms brittle balls.	slightly dark: forms weak ball: crumbly.	slightly dark, forms weak balls: clods crumble
less than 20%	very dry: loose, flows through fingers.	dry: loose, flows through fingers.	light color: powdery, dry.	hard, baked, cracked, light color.

A more specialised technique for determining water requirement of plants given soil moisture values (mm/m depth) is outlined below. This technique, termed a site water balance, may be used to calculate required irrigation water. Knowledge of the plant available soil water, (the amount of water that exists within the profile between *FC* and *WP*) plus rainfall and/or irrigation amount and a calculation of tree water use *(ET)* allows calculation of the total water available to the plants and therefore how long until irrigation will be required again.

If some simple characteristics of the soil are known, these can be used to determine the irrigation requirement. Such characteristics can be obtained through knowledge of the type of soil predominant in the orchard and measures such as soil *bulk density* which may need to be carried out by a consultant. To determine the irrigation water requirement, the depth of water to be applied (net water requirement, NWR) must be determined.

NWR = (FC-WP) x BD x 10 x RZ

Where

NWR = net water requirement (mm)
FC = *Field capacity*
WP = *Wilting point* or *Stress point*
BD = *Bulk density*
RZ = root zone depth (m)

The net water requirement is then multiplied by the crop coverage area to determine the irrigation water requirement. In this calculation water amount to be applied is estimated as mm.

As a quick reference 1L of water spread over 1 m^2 of soil gives 1mm water applied.

Rooting depth of summerfruit trees is generally assumed to be in the top 1m or 1000mm of soil.

If an irrigation interval is required the net water requirement can be divided by the *crop evapotranspiration* which will produce this information. The following site has further information on using soil characteristics when managing irrigation practices.

http://cru.cahe.wsu.edu/CEPublications/pnw0475/pnw0475.html

Other useful links for irrigation scheduling techniques
http://www.al.gov.bc.ca/resmgmt/publist/500series/577100-1.pdf

2.1.3 Irrigation scheduling using consultancy services

Technology such as Diviner equipment and Neutron probes may also be used to measure soil moisture and therefore schedule irrigation. These devices are both expensive and not straightforward to use. Therefore the use of these technologies needs to be done in conjunction with horticultural consultant expertise. Fruition Horticulture offers a scheduling service using the Diviner system.

Diviner

The Diviner system integrates the total amount of water within the root zone and is dependant on the depth to which the probes are inserted. In simple terms the device records the *dielectric constant* of the soil that it is in contact with the probe. The more water in the soil matrix, the higher the *dielectric constant* of the water/soil matrix. In a dry soil the *dielectric constant* is reduced. More information on the diviner system can be accessed from the link below http://www.sentek.com.au/products/diviner.asp

Neutron Probe

Neutron probes use material such as Americium-241-beryllium as the source of fast neutrons. Hydrogen atoms (present in water (H_20)) has the same mass as the high energy neutrons present in the probe. The majority of hydrogen in soil is associated with soil water. Therefore, when the fast neutrons collide with hydrogen, the fast neutrons lose enough energy to become slow neutrons that rebound back to the probe where they are absorbed by the nucleus of the gas in the probe. Boron tri-fluoride or helium-3 gas can be used to absorb the rebounding slow neutrons. The amount of water and thus amount of H in the soil dictates the number of slow neutrons recorded by the probe and is therefore indicates soil moisture content.

2.1.4 Measurement of plant water status

The measurement of plant water status is a good way to determine whether or not irrigation is required. However it is complex to carry out and is not generally done by growers. Readings obtained from a *pressure bomb*, is strongly dependent on time of the day when the measurements are taken. For example midday readings may indicate a water deficit even though the soil water content is high. This occurs because the pull for water by the dry atmosphere is greater than the water that can be delivered to the canopy via the roots and the water transport system in the trunk and stems, and leaves will temporarily wilt until stomata close and leaf turgor is regained.

The diagram below illustrates a commercially available model of a *pressure bomb*. More information can be accessed from http://ictinternational.com.au/saps.htm.

Heat pulse technology is less dependent on time of day as measurements are continuously made throughout the diurnal cycle. However these devices are expensive and numerous sets need to be installed within an orchard in order to get meaningful values which can be used for scheduling irrigation. This technique is not routinely used by growers in New Zealand but is often used by researchers investigating irrigation strategy. The technique is suitable for tree crops such as summerfruit and some vine crops including grapes.

2.1.5 Additional information

2.1.3.1 The calculation of *reference ET (ET_0)*

There are various techniques available to determine reference ET including measurement of *pan evaporation* and using measured climatic data via the Penman–Montieth equation.

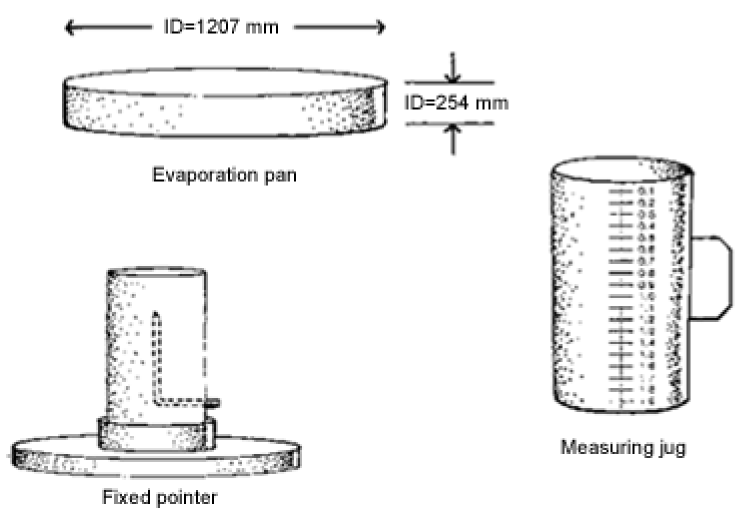
The link below provides a more detailed discussion of the use of *crop coefficients*, further discussion of *ET* calculations and the *crop coefficients* for a range of production crops including summerfruit.

http://www.fao.org/docrep/X0490E/x0490e0b.htm#tabulated%20kc%20valuesF

For a more general over view of how *crop coefficients* are used in irrigation scheduling the following link may be useful.
http://www.irrigationbc.com/images/clientpdfs/577100-5.pdf

i. Pan Evaporation

A pan evaporator, which measure pan evaporation, is a form of evaporimeter that measures the amount of water which evaporates from a pre-determined surface area. The pan evaporation method is based on the principle that in the absence of rainfall, the amount of water evaporated daily (mm day^{-1}) from an open water surface is the integrated effect of the sun, wind velocity, temperature and humidity. To measure pan evaporation, water loss from a standardised evaporation pan is determined daily or weekly. The diagram below illustrates the components of a standard evaporation pan.



This measure of evaporation from the pan is first adjusted for pan characteristics using a *pan coefficient* before it can then be used to determine the *crop ET* with the use of a *crop coefficient*.

$ET_0 = K_p \times E_{pan}$

Where: ET_0 = reference ET, K_p = Pan coefficient, E_{pan} = Pan evaporation

Another form of evaporimeter is an *atmometer*. As with Pan evaporation method, data from an *atmometer* needs to be adjusted before it can be used to determine ET_c. The following website provides a more detailed description of *(E_{pan})* and *pan coefficients (K_p)*. http://edis.ifas.ufl.edu/AE118

ii Pennman – Montieth equation

Reference ET (ET_0) can be determined by using measured *metrological* data which may be obtained from a nearby weather station. ET_0 can then be determined from this data using the Penman-Monteith equation.

The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data in order to calculate *reference ET*. If more detail is required on the Penman-Monteith technique the following link provides further information.
http://www.fao.org/docrep/X0490E/x0490e06.htm#TopOfPage

2.2

Methods of irrigation

Determining the type of irrigation system to be used depends on factors such as soil type, crop type, planting density, water quality, irrigation equipment at hand, and economic factors such as the capital cost and operating cost. Below are descriptions of various types of irrigation systems and possible benefits and disadvantages.

2.2.1 Drip/trickle/micro-jet

Description:
Polythene pipes and emitters deliver water directly to the soil immediately under the tree. The crop is irrigated frequently, often daily to maintain a constant plant available soil moisture. Water is only applied to the tree line with a maximum of 40-50% of the orchard floor being irrigated.

There are a number of factors that should be considered when deciding between micro irrigation systems. These include:

- Soil type

    - In situations where a lot of water loss may occur due the soil being highly permeable, dry or cracked clays, micro-jet emitters may be more appropriate than trickle lines.
    - In drought prone soils a reservoir of water within the soil profile maybe beneficial in case of equipment failure. In this case micro-jets maybe more appropriate than drip or trickle irrigation.
- Weather conditions
    - In high wind areas where water may be blown off target, trickle or drip irrigation may be more appropriate than microjets.
- Water quality
    - As some micro irrigation systems are susceptible to blockages, in areas where the water quality may be marginal, micro-jet or micro sprayers maybe more appropriate. These are less likely to block and any blockages can be observed easily and fixed quickly.

Benefits:

- Drip irrigation allows water to be delivered directly to the root zone of the tree with little water wastage through evaporation or wetting soil areas which are not occupied by tree roots.
- Leaves and fruit remain dry so disease problems are potentially less than with overhead sprinklers where foliage is wetted.
- The system is permanent so once installed irrigating is straight forward.
- Drip irrigation works well in conjunction with *fertigation.*
- Irrigation techniques such as *RDI*, which may improve the quality of the fruit and reduce water usage, can easily be implemented.
- Irrigating only the tree line ensures traffic access to the orchard at all times for essential operations such as spraying and harvesting
- A low pressure system which is relatively energy efficient.

Disadvantages:

- Cost of installation
- The main issue is blockage of emitters and so it is vital that adequate filtration and chlorination systems are installed and the system is run in accordance with manufacturers instructions.
- Not suitable for frost protection.
- This irrigation method requires the soil to be maintained at a constant moisture level and therefore more extensive monitoring of soil moisture is required.
- Lack of root development if the correct emitter and number of emitters are not installed. These systems are not designed to apply water to large root systems and therefore two to three lines may be required per row of trees.
- Limited wetting zone so not appropriate for use on light soils with low *WHC*

2.2.2 Over head sprinkler

Description:

Pipes buried in the ground with risers and impact sprinklers above the ground. This system applies water to the entire tree and orchard floor

Benefits:

- Application of foliage or fruit remedies such as calcium chloride which may reduce cracking in cherries.
- Works well with the use of fertigation.
- May be used on flat to sloping topography in virtually any climate.
- Can be used for frost protection.
- Low labour requirement.
- More efficient use of water than flooding system.

Disadvantages:

- High initial capital cost to set up.
- Traffic access during irrigation may be limited.
- Burning of leaves may occur if salt levels in the water are high.
- Less efficient use of water compared to micro sprinkler, jet or drip systems.
- Pest and disease levels may increase due to wetting of the foliage.
- Sprinklers are not readily accessible and therefore access for repairs and maintenance can be time consuming.

2.2.3 Movable pipes

Description:
These systems employ a lateral pipeline with sprinklers installed at regular intervals and a quick coupling system to aid pipe movement and placement. The sprinkler lateral is placed in one location and operated until the desired water application has been made. Then the lateral line is disassembled and moved to the next position to be irrigated. Many benefits and disadvantages as per the fixed sprinkler system.

Benefits:

- Total system capital cost is relatively inexpensive

Disadvantages:

- Highly labour intensive and high labour costs
- Traffic access during and after irrigation limited due to pipes and wetness of soil in traffic area.

2.2.4 Flooding

Description:
Large amounts of water are diverted to the orchard through a series of open drains. Used when water is plentiful, runoff can be returned to the delivery system and is of high enough quality to be reused. Flood irrigation is typically used when slopes are mild enough to prevent erosion, but steep enough to ensure water reaches the bottom end of the field without over-saturating the top end of the field.

Benefits:

- Many properties in the Hawkes Bay have this system already set up and the cost of replacing it is high.
- Not labour intensive

Disadvantages:

- Traffic access during irrigation may be limited for cultural operations, particularly spraying and harvesting, for several days after watering.
- Inefficient use of water.
- Wasteful use of water encourages excessive percolation beyond the root zone in permeable soils. This loss of water below the root zone carries nutrients with it which may then contaminate groundwater resources.
- When used on soils with low permeability water must be applied for long periods of time and there is a tendency for water logging and reduced aeration in soil, both of which are detrimental to tree health.
- Usually less efficient than sprinkler, micro or drip irrigation systems.
- Does not allow accurate control over the rate of application, i.e. cannot supply more or less water.
- Makes it difficult to avoid over cultivation of soil and resultant breakdown of its structure.
- Causes uneven watering due to differing infiltration rates in areas with variation in soil types within an irrigation shift.
- More labour intensive that automated systems.
- Promotes weed growth and hinders control efforts.
- Does not allow *fertigation.*

Sites where information was obtained and further details available
http://www.rainbird.com/iuow/tips/tips_ag.htm
http://www.savewater.com.au/index.php?sectionid=566
http://www.wateright.org/site2/publications/880105.asp
http://pubs.caes.uga.edu/caespubs/pubcd/B882.htm
http://www.ext.colostate.edu/pubs/crops/xcm173.pdf

2.3

When are the best times to irrigate

Often irrigation is applied in abundant quantities to avoid any water stress developing in trees. However, too much water can be detrimental not only to tree health and fruit quality (due to disease incidence in a humid orchard environment and excessive vegetative growth), but it can also damage soil quality through water logging and compaction and compromise ground water quality as nutrients leach from the root zone.

In summerfruit there a 3 distinct stages of fruit growth (Fig.2) and this therefore allows *regulated deficit irrigation (RDI)* strategies which may reduce vegetative growth without detrimentally impacting on fruit growth.

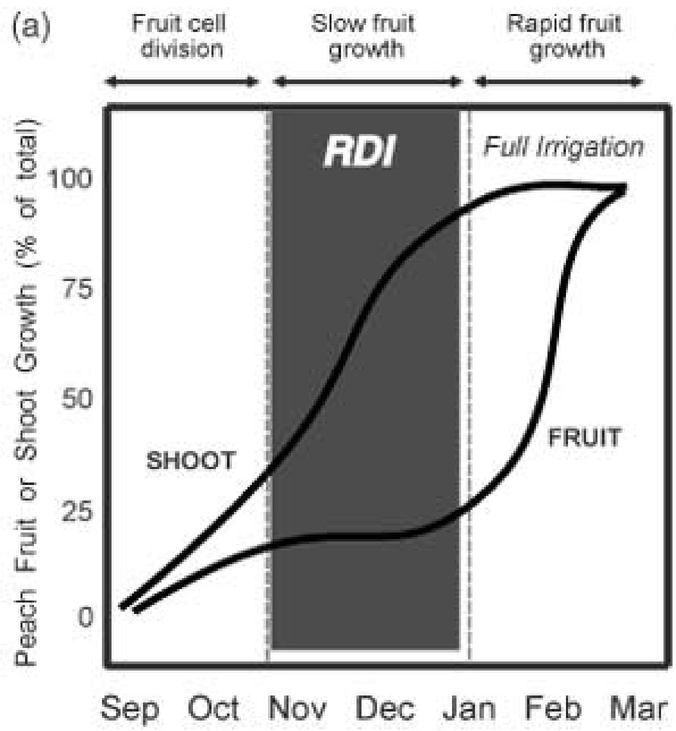


Fig.3 The 3 stages of fruit growth through the season and the corresponding shoot growth of Peach

We see from this graph that in peach most of the shoot growth occurs during stage 2 whereas fruit growth dominates in stage 3. During stage 2 pit hardening is occurring in fruit and so little fruit growth is recorded over this stage. The separation of the growth stages of fruit and shoots allows irrigation control during stage 2 to impact on vegetative growth with little or no detrimental effect on fruit.

Most summerfruit are drought tolerant during stage 2. However, drought conditions during stages 1 and 3, especially stage 3, may lead to a reduction in fruit growth and final fruit size. Trees also need to be well supplied with water following fruit harvest as *flower initiation* for the coming season is occurring at this time.

Different summerfruit crops vary in the length of each stage and in the rate of fruit maturity which may range from December through to March. These differences in *phenological* timing will influence actual amounts of irrigation applied and the efficacy of *RDI* strategies.

Visit the following sites for more information on *RDI*

http://www.fao.org/docrep/004/Y3655E/y3655e10.htm

http://www.dpi.vic.gov.au/DPI/nreninf.nsf/childdocs/-2BAF4D73531CD1544A2568B3000505AF-FFB44D93F7BB6C37CA256C4A0083CDB7-0123B04778E33BD84A256DEA0027B8C3-7CFFC08532C75D0ACA256BCF000BBF59?open